# Harbor/Mooring Harbor Defense Concept

David L. Bradley - PI
The Pennsylvania State University/Applied Research Laboratory
State College, PA 16804-0030
Phone:(814) 863-9916  Fax: (814) 863-8783  E-mail: dlb25@psu.edu

Kyle M. Becker - Co-PI
The Pennsylvania State University/Applied Research Laboratory
State College, PA 16804-0030
Phone:(814) 863-4159  Fax: (814) 863-8783  E-mail: kmbecker@psu.edu

## LONG-TERM GOALS

The long-term goal of this work is an integrated defense system that provides protection of Navy assets, while in port, from the threat posed by covert swimmers.  The general concept is to hail, deter, and/or incapacitate the threat by directing a controlled level of low-frequency acoustic energy at the target location.  At the system level, the concept requires combining elements of target detection, classification, and tracking, localized fire control to direct acoustic energy using emplaced acoustic sources, and sources capable of delivering energy commensurate with the extant defense requirements.

## OBJECTIVES

An objective of this work is to examine the feasibility of putting a requisite level of acoustic energy on target in a real harbor environment.  This object addresses the question: can a dynamic complex acoustic field be directed onto a target with enough energy to cause deterrence, disablement, or physical damage to cause abortion of the swimmer mission?  In addition, a prototype is to be developed with graphical user interface including target tracking information and source control capabilities to put energy on target.  A working system for control of the acoustic field and putting energy on target will be demonstrated during the 3$^{rd}$ quarter of 2008.

## APPROACH

The approach involves efforts in directive source and acoustic propagation modeling, mobilization of appropriate low-frequency acoustic sources (by acquisition or prototype design), assembly and testing of equipment for validation in a controlled environment, and final prototyping and testing in an operational environment.  To meet the proposed objectives, a multi-phased approach was taken including analytic and numerical computations along with experimental validation.  The work progressed from understanding the requirements of, and demonstrating numerically, the ability to direct and propagate low-frequency acoustic energy in a simple 2-D waveguide, to a prototype system test in an operational environment.  A component of the effort involves integrating proposed source characteristics/configurations/control into the numerical modeling codes.  Another major factor will be establishing an adaptive computational framework for calculating acoustic energy loss that responds to

# Report Documentation Page

| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **30 SEP 2008** | **Annual** | **00-00-2008 to 00-00-2008** |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| **Harbor/Mooring Harbor Defense Concept** | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | 8. PERFORMING ORGANIZATION REPORT NUMBER |
|---|---|
| **The Pennsylvania State University,Applied Research Laboratory,State College,PA,16804-0030** | |

| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
|---|---|
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
**Approved for public release; distribution unlimited**

**13. SUPPLEMENTARY NOTES**
**code 1 only**

**14. ABSTRACT**

**The long-term goal of this work is an integrated defense system that provides protection of Navy assets, while in port, from the threat posed by covert swimmers. The general concept is to hail, deter, and/or incapacitate the threat by directing a controlled level of low-frequency acoustic energy at the target location. At the system level, the concept requires combining elements of target detection, classification, and tracking, localized fire control to direct acoustic energy using emplaced acoustic sources, and sources capable of delivering energy commensurate with the extant defense requirements.**

**15. SUBJECT TERMS**

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT **unclassified** | b. ABSTRACT **unclassified** | c. THIS PAGE **unclassified** | **Same as Report (SAR)** | **8** | |

spatial and temporal characteristics of the harbor environment in conjunction with the sources proposed/used for the program. In particular, for harbor acoustic characterization, the low frequency harbor acoustics and harbor transfer function must adapt to the repositioning of source(s), tidal and other diel variations, and movable scatterers (such as ships).

The initial phase of work effort was an expanded feasibility study of acoustic transmission calculations in idealized harbor-like environments. For a given source configuration and environment, formation of an acoustic *hot zone* was evaluated by contour levels indicating intensity and extent of regions corresponding to where a swimmer would likely detect the signal, be deterred, or be incapacitated (exact levels to be determined in a separate study, but a preliminary literature search suggests 140 dB re 1 uPa for diver awareness of irradiation and (TBD) dB for immobilization [1].) The feasibility and relative efficiency of different source types was investigated analytically and numerically for both narrow- and broad-band signals. Sources were integrated into a common "benchmark" harbor model environment for comparison of the computed acoustic fields. Modeling was also used for determining the location, number, and power requirements of acoustic sources necessary to achieve dynamic focusing capabilities in a given harbor environment. Source capability was be demonstrated numerically by plots of acoustic intensity as a function of location.

Modeling efforts have continued over the duration of this project. Propagation modeling efforts started with an idealized 2-D harbor environment incorporating very simple boundaries and typical harbor depths. The calculations were extended to more complex environments, by varying the harbor bottom type, adding thermoclines, introducing ships and including permanent harbor structures such as piers or breakwaters. The latter cases, which represent the introduction of strong acoustic scatterers into the environment, show the enhancement/degradation and/or displacement of the *hot zone* caused by including typical harbor structures. Initial 2-D waveguide modeling efforts progressed to 3-D modeling work in order to make predictions for the specific harbor environment where demonstration project will be conducted. As dictated by the chosen harbor environments, as features are added, modeling progressed, from traditional approaches used in ocean acoustic propagation modeling such as normal modes or parabolic equation methods, to more general finite element or boundary element methods [2]. The overall effort has required dedicated computational facilities as well as the potential for a significant effort in adapting or developing propagation codes to meet project requirements. At project completion, the accumulated modeling capabilities will be repackaged to provide harbor deterrent system design capabilities for specific ports. The design system prototype will be configured and provided for Navy and Coast Guard use.

Experimentally, the work progressed from a controlled study to an operational prototype. A system prototype was demonstrated in a real harbor in summer 2008. In FY 06 and 07, after demonstrating numerically the ability to focus energy in relatively simple environments, computational results will be validated by experimental work in controlled environments. These tests demonstrated, using sources and an array of receiving hydrophones, that an acoustic *hot zone* can be created and dynamically controlled within a simple waveguide. At this stage, the work demonstrated the ability to deliver a stepped level of acoustic intensity to a specified interrogation region. Demonstration and engineering tests progressed from fully controlled environments such as laboratory test tanks, an outdoor flooded quarry (Jacksonville, PA), to a real harbor environment (Coddington Cove, Newport, RI).

In FY 08, a demonstration in a real harbor environment with a prototype system was planned and executed. The harbor location was Coddington Cove, Newport, RI. The required effort prior to an operational environment demonstration is extensive. For a real environment and a convincing

prototype, it is important to demonstrate subsystem linkage, total system integration and simplicity of use, in addition to the obvious metrics of capability. Acoustic sources and the receiving array of hydrophones were adapted from fieldwork completed in 07. The scope of the prototype system will include demonstrating a response at the location of swimmers, swimmer delivery vehicles (SDVs) or other targets. For validation purposes, using the modeling tools developed in the previous years, data/model comparisons were made for the specific harbor environment chosen for the demonstration.

**WORK COMPLETED**

In FY2007 an engineering field test was conducted in Jacksonville Quarry, Jacksonville, PA, located about 30 miles East of State College, PA. It was demonstrated that an acoustic beam could be formed using an array of 4 Lubell sources. In preparation for an engineering test in July 2007 at Coddington Cove, a hydrophone measurement system was specified and purchased. 12 Reson TC-4032 hydrophones were purchased with a receive response down to 5 Hz. In addition, a self-contained multi-channel signal distribution and conditioning system was designed and built. The hydrophone measurement system was field tested at Coddington Cove in July 2007. An array of 12 hydrophones was laid out along 4 radials with the assistance of the range-crew and Navy certified divers from NUWC. The origin of the radials was a source monitoring phone mounted on the different sources at a distance of 1 m. Several different sources were used during the test including an HLF-1, slotted cylinder, J-15-1, J-9, and J-11 sources. The focus of this work was to examine propagation conditions for a single source along radials with different aspects in the harbor. CW tones ranging from 10 Hz to 1000 Hz were projected during the tests in order to determine the cutoff frequency for propagation. In addition LF linear sweeps from 50-1000 Hz were broadcast from a range craft at different locations in the harbor to examine spatial variability of propagation conditions and any contributions to the field from strong reflectors such as the moored carriers, piers, or breakwaters. Sound speed profile measurements were made twice a day by deploying a CTD from the range craft.

Along with the engineering test at Coddington Cove, supporting archival environmental data were assembled and reformatted for use in 3D acoustic propagation models. Electronic navigational chart data was acquired from the NOAA office of coast survey. Additional high-resolution bathymetry data and surficial sediment data was provided by NUWC. Along with the measured water column sound velocity data a spatial gridding of the harbor environmental properties was achieved. The original data, given on a semi-regular grid was then interpolated onto a finite element mesh grid over the later extent of the harbor. At each of the node points of the mesh, normal modes were calculated using Kraken[3]. With the modes calculated, the field could be simulated for any source location placed in the mesh using the pre-determined modes calculated at the mesh locations.

In the spring of 2008, this system was augmented by a National Instruments system to provide real-time acquisition and monitoring capabilities that were not available during the July 2007 test. Further, this system provided the base from which a graphical user interface (GUI) was developed for the demonstration. The GUI is discussed further in the results section. For the demonstration test a fixture was designed from which four (4) J-15-3 and three (3) HLF-1D low frequency acoustic sources were
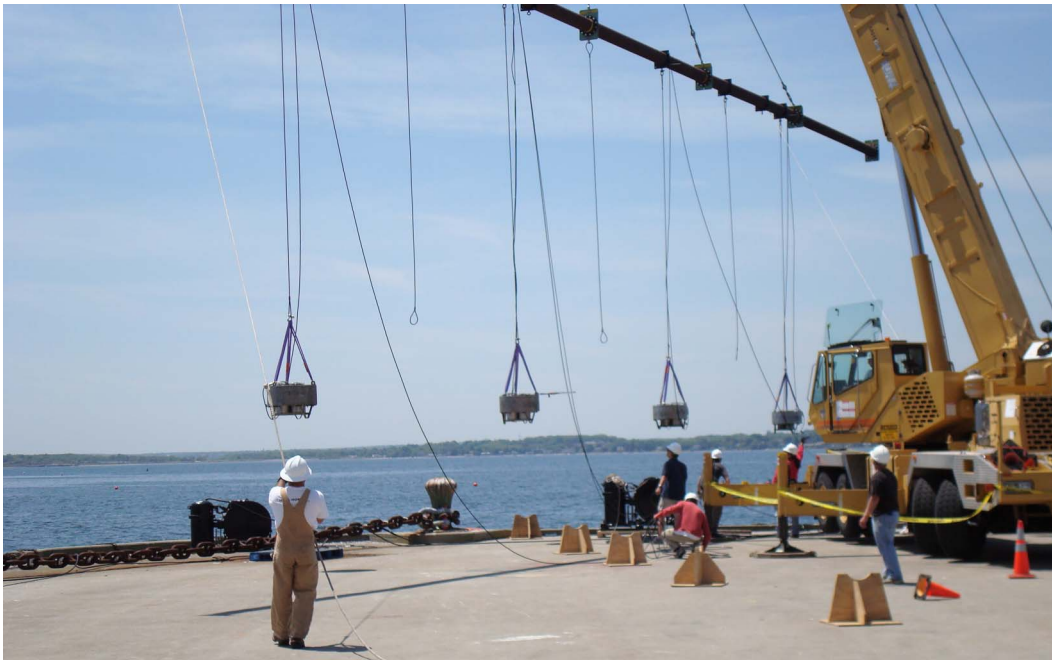
*Fig. 1 Source fixture suspended above pier with 4 J-15-3 low-frequency projectors.*

suspended in a linear array.  The fixture was designed to hold all seven projectors and allow for a total aperture of 120 ft.  The fixture with only the 4 J-15-3 sources mounted is shown in Fig. 1.  Close examination of the figure indicates hydrophone locations in the channel which are marched with orange buoys.

**RESULTS**

The prototype graphical user interface for control and display of acoustic signals during the Coddinton Cove demonstration test is shown in Fig 2. The GUI displays transmit frequency, amplitude, and phase information for the signals sent to the deployed sources.  Yellow, light green, and red dots indicate positions of hydrophones within the cove.  The acoustic level received at each of the phones is indicated both numerically and graphically at the top of the interface.  A blue rectangle at the top-left corner of the display represents the location of a covert swimmer.  From the GUI, the swimmer can be commanded to 'swim' from Coddington Point, in the top-left corner of the display, to the Coast Guard pier at the bottom right.  The path of the swimmer was populated with hydrophones.  As the swimmer passed a particular phone along the line, acoustic energy was directed to that point by adjusting the phases of the individual sources.  The phone with the highest receive level of acoustic energy turns red as the swimmer passes by.  Although the swimmer was virtual, the demonstration showed the ability to sweep a beam of acoustic energy across the line of hydrophones along the track.  Further details of the control aspect of this project are provided by our collaborators.

In addition to demonstrating the ability to control low frequency sources in a harbor, an assessment was made of the amount of energy on target, transmission loss, and temporal variability.  As indicated by the level indicator for hydrophone 3 in Fig 2, a receive level of nearly 160 dB was observed at the target location for this run.  This was well above the expected level of 145 dB at 100 Hz that could be expected to have an impact on a diver.  TL was measured at frequencies between 50 and 600 Hz to

determine the best frequency for propagation in the environment. Measurements made using both
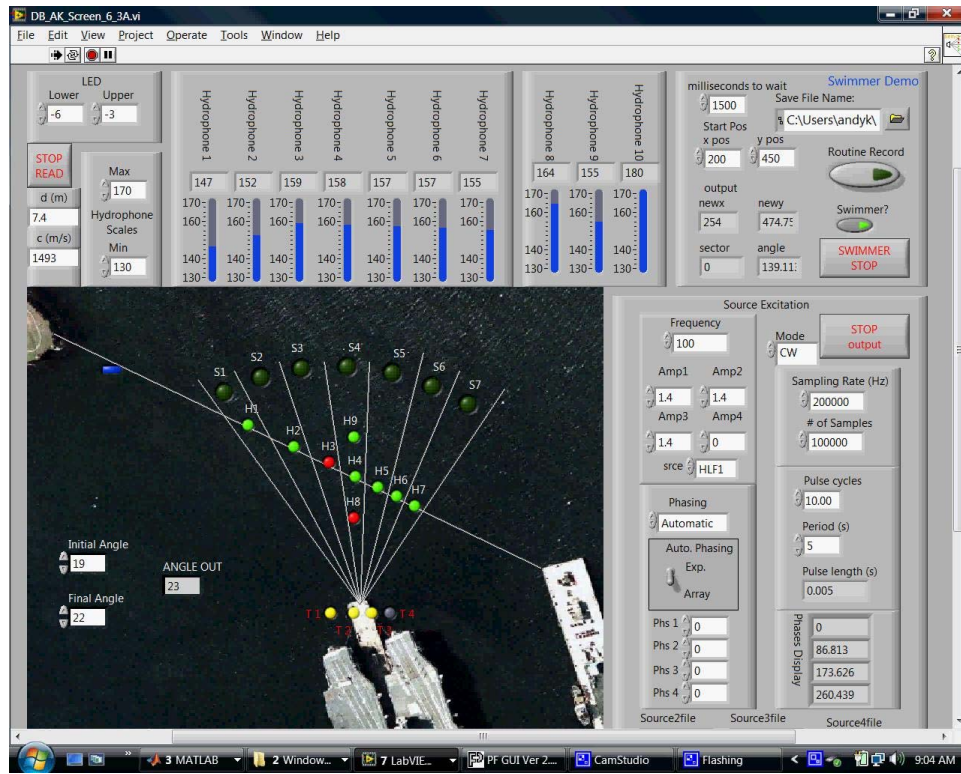


***Fig. 2 Prototype user interface for data acquisition and control of acoustic sources implemented during Codding Cove UTN Demonstration, May/June 2008. Linear array of dots spanning cove from top-left corner to Coast Guard pier in lower right are locations of hydrophones 1 – 7 placed to represent track of covert swimmer. Red dots indicate hydrophones with highest receive level for transmit conditions.***

J-15-3 and HLF-1D sources indicated that propagation was best at 100 Hz as shown in Fig 3. Measured TL was also used to verify prediction modeling capabilities developed as part of this work. Based on a three-dimensional parameterization of the harbor environment in terms of bottom depth, sound speed in the water column, and sound speed in the sediment, the acoustic field was predicted using a normal mode code [3] at 100 Hz.  TL for the predicted acoustic field is shown in Fig. 4 along with the location of the hydrophones during the demonstration.  TL predicted by the model along the

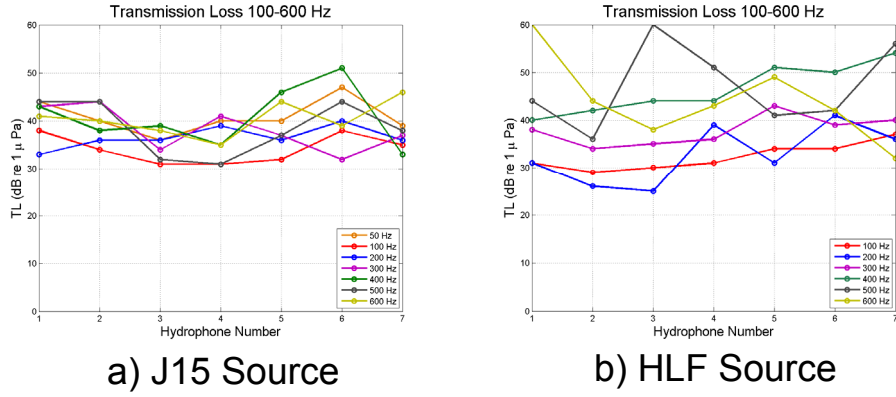## a) J15 Source            b) HLF Source

***Fig. 3 Transmission Loss measured along swimmer track. a) TL measured for J-15-3 source indicated propagation to be best at 100 Hz. b) TL for HLF source was generally noisier than J-15 source due to higher frequency resonances, but propagation at 100 Hz was again best.***
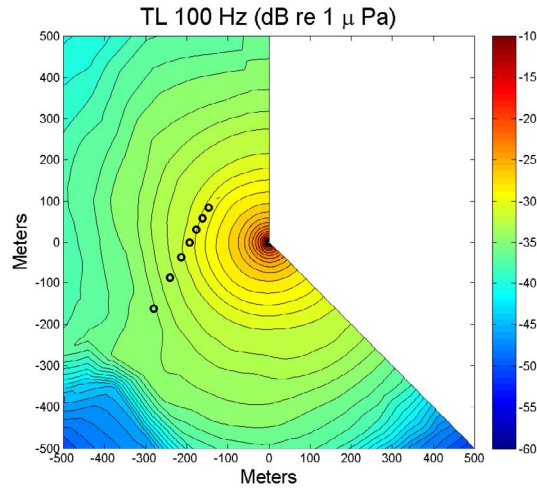


***Fig. 4 TL predicted by 3D normal mode model with experimental hydrophone locations indicated by open circles.***

hydrophone array was between 30 and 38 dB which is in excellent agreement with the data in Fig. 3. The prediction model is configured to accept updated sound velocity profiles as they become available during operations.  In addition, the model has been run for water depths representing the entire range of tidal variations observed during the test.  The tidal variation was only on the order of 1.5 meters during the test and resulting in TL variances of ~2 dB at 100 Hz.  Nevertheless, the prediction model is designed to adapt for tidal variability that may be important at other frequencies and/or other harbor locations.  In addition to the propagation measurements, ambient noise measurements were taken throughout the test period during times when the sources were quiet.  The spectral level of ambient noise as a function of frequency averaged over hydrophones 1 – 7 and over the course of the day is shown in Fig. 5.  The observed levels, plotted on the Wenz curves indicate the quiescent state of the harbor to be noisy relative to open ocean, yet sufficiently low to not impede against using low-frequency acoustic energy to interdict a covert swimmer.
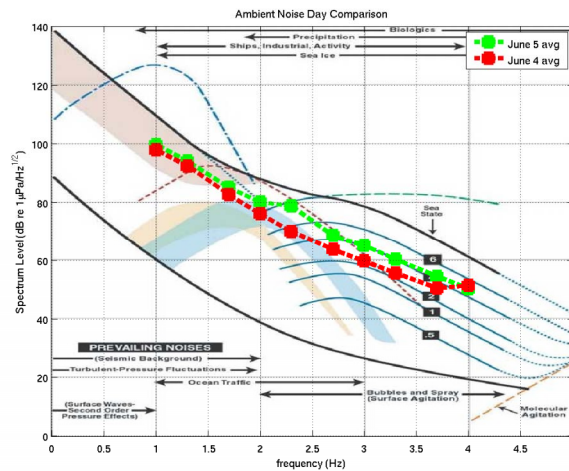
***Fig. 5 Spectral Level verses frequency of ambient noise measured over two days in Coddington Cove.***

## IMPACT/APPLICATIONS

Successful demonstration of the integrated defense system will provide a means for the Navy to protect valuable assets in port from the threat posed by covert swimmers. It is anticipated that systems of this type be installed initially in military harbors within the US. Installations would expand to deployment in military and important commercial harbors around the globe.

## TRANSITIONS

## RELATED PROJECTS

Turbo Machinery Acoustic Souce, M. Jonson (PI), Penn State University

Defense of Harbor and Near-Shore Naval Infrastructure, G.H. Koopman (PI), Penn State University

Human Lung Response to Low-Frequency Underwater Sound, M. Hamilton (PI), Univ. of Texas Austin

NRL GelMan Underwater Surrogate, K. Simmonds (PI), Naval Research Lab.

Underwater Acoustics Bioeffects: Continuous Wave, E. Cudahy (PI), Naval Submarine Medical Research Lab.

## REFERENCES

[1]  J.S. Martin, P.H. Rogers, and E.A. Cudahy, Measurement of the depth-dependent resonance of the water-loaded human lungs, *J. Acoust. Soc. Amer.*, **117**(4) (2005)

[2]  F.B. Jensen, W.A. Kuperman, M.B. Porter, and H. Schmidt, *Computational Ocean Acoustics*, (AIP Press, New York, 1994)

[3] M.B. Porter and E.L. Reiss, A numerical method for bottom interacting ocean acoustic normal modes, *J. Acoust. Soc. Am.,* **77**, pp. 1760-1767 (1985)